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Isokinetic Strength of Rotators, Flexors and Hip Extensors is Strongly Related to Front Kick Dynamics in Military Professionals

by

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Achieving the maximum possible impact force of the front kick can be related to the isokinetic lower limb muscle strength. Therefore, we aimed to determine the regression model between kicking performance and the isokinetic peak net moment of hip rotators, flexors, and hip extensors and flexors at various speeds of contraction. Twenty-five male soldiers (27.7 ± 7.2 yrs, 83.8 ± 6.1 kg, 180.5 ± 6.5 cm) performed six barefoot front kicks, where impact forces (N) and kick velocity ($m \cdot s^{-1}$) were measured. The 3D kinematics and isokinetic dynamometry were used to estimate the kick velocity, isokinetic moment of kicking lower limb hip flexors and extensors (60, 120, 240, 300$° \cdot s^{-1}$), and stance lower limb hip internal and external rotators (30, 90$° \cdot s^{-1}$). Multiple regression showed that a separate component of the peak moment concentric hip flexion and extension of the kicking lower limb at 90$° \cdot s^{-1}$ can explain 54% of the peak kicking impact force variance ($R^2 = 0.54$; $p < 0.001$). When adding the other 3 components of eccentric and concentric hip internal and external rotations at 30$° \cdot s^{-1}$, the internal and external hip rotation ratios at 30$° \cdot s^{-1}$ on the stance limb and the concentric ratio of kicking limb flexion and extension at 300$° \cdot s^{-1}$ that explained the variance of impact force were 75% ($p = 0.003$). The explosive strength of kicking limb hip flexors and extensors is the main condition constraint for kicking performance. The maximum strength of stance limb internal and external rotators and speed strength of kicking limb hip flexors and extensors are important constraints of kicking performance that should be considered to improve the front kick efficiency.

Key words: *strike, self-defense, impact force, peak moment, resistance training.*

Introduction

The self-defense of civilians and military personnel includes tactical and technical skills, where the front kick is the most common strike used in close combat (Vágner et al., 2018). Particularly, military personnel use this movement pattern because they often carry equipment in their hands and are wearing backpacks. To eliminate the attacker, the goal of a front kick is to achieve the maximum possible impact force (IF_{peak}) when the foot hits the target, requiring strong and fast muscle action of the lower limb. However, there is limited information

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regarding which muscle groups should be trained to improve the efficiency of the front kick.

An efficient front kick is related to the technique, movement control, speed, velocity, force, energy and power (Maszczyk et al., 2018; Ramakrishnan et al., 2018; Serina and Lieu, 1991; Vágner et al., 2018), where those components are determined by the quantity of transferred momentum or energy (Dworak et al., 2008). Thus, many researchers have investigated the kinetics and kinematics of front kicks (Mori et al., 2002; Pozo et al., 2011; Wasik et al., 2015). The techniques of the front kick begin from the center of the body by flexion in the hip and knee joints and forward-kicking leg thigh acceleration. Furthermore, the movement of the thigh slows down and the knee joint accelerates the movement of the foot in the direction of the impact (Sorensen et al., 1996). In the analysis of the individual parts of the front kick, the highest torque was observed in the hip joint flexors (Hip_{flex}) in the first phase of the kick; however, in the second phase, the hip extensor (Hip_{ext}) and knee extensors dominated. The largest moment was observed about the hip joint with the next highest being produced about the knee joint (Hwang, 2008). Despite detailed descriptions of the front kick technique, no study has investigated the relationship of kicking performance to hip joint rotation (Hip_{Rot}), which is the important part of other types of kicks (Sujae and Koh, 2010) and might be an important contributor to front kicking efficiency.

The muscle groups, which are tested for the isokinetic net moment output, are selected according to their contribution to specific movement tasks, e.g., Hip_{flex}, Hip_{ext}, knee extensors and abductors have been found to be important during front kicking (Busko, 2016; Jung et al., 2017), where different combat sport athletes showed similar peak Hip_{flex} and Hip_{ext} moment values (Busko, 2016). Although the front kick primarily comprises fast muscle action, no study has focused on whether maximum, explosive or speed strength determines the IF_{peak} in a front kick. This may be done by isokinetic measurement at different speeds and types of contraction (Stastny et al., 2018), where low, medium and high speed indicate the athletes' maximum strength, explosive strength and speed strength, respectively. In addition to Hip_{flex} and Hip_{ext} of the kicking limb, the Hip_{Rot} moment of the stance limb might be useful to describe a soldier’s ability to perform front kicking because their strength has been related to dynamic stability (Gordon et al., 2013). To our best knowledge, the current literature does not summarize how large is the muscle contribution of a stance and a kicking lower limb to front kicking performance and what type of the force/velocity relationship should be applied for valid isokinetic strength testing in subjects trained in front kicking.

Achieving the maximum possible impact force of the front kick can be related to the isokinetic lower limb muscle strength, where there are no current guidelines regarding which muscle groups and testing velocities are crucial for kicking performance. Therefore, we aimed to determine the regression model between kicking performance (represented by the total force impulse, V_{imp} and IF_{peak}) and isokinetic peak net moment of internal Hip_{Rot} and external Hip_{Rot} Hip_{flex}, and Hip_{ext} at various speeds of contraction ($30°\cdot s^{-1}$, $60°\cdot s^{-1}$, $90°\cdot s^{-1}$,$120°\cdot s^{-1}$, $240°\cdot s^{-1}$ and $300°\cdot s^{-1}$).

Methods

The present investigation was a cross-sectional study performed at the Biomechanics Laboratory of Extreme Loading at the Charles University in Prague, Faculty of Physical Education during a special military forces self-defense camp (February, 2017). Following a familiarization session, participants reported to the laboratory and performed two series of six maximal effort front kicks against a vertically anchored force plate, followed by one day of rest and isokinetic strength measurement. The participant performed all front kicks barefoot by their dominant lower limb, which was estimated by asking about the preference of soccer and combat kicking. The research was approved by the Ethics Committee of the Faculty of Physical Education and Sport (No. 50/2018); furthermore, informed consent was signed by all the participants. The procedures were performed in accordance with the Declaration of Helsinki 2013.

All front kick dynamics measurements were completed in approximately 40 min. The dynamic warm-up lasted 10 min, and each participant performed a pretest of five kicks in the power plate before the experimental measurement. The familiarization session was also used to measure the distance from the force plate for each participant to execute each kick in the same, comfortable position during testing. These individualized distances were then recorded and used to ensure the same starting position for each kick. All front kicks began with a front posture and were executed so that the foot made contact at a mid-range height, typically the abdomen or solar plexus (Vágner et al., 2018). Participants executed two sets of six front kicks, with instructions to kick as fast and as hard as possible to the target (force plate). Between each kick, the participant was given 30 s rest intervals (Vagner et al., 2018), and there was a 5-min rest interval between particular sets of kicks.

Participants

Twenty-five professional soldiers (age: 27.7 ± 7.2 yrs, body mass: 83.8 ± 6.1 kg, body height: 180.5 ± 6.5 cm) from the Military Department at the Faculty of Physical Education and Sport, Charles University in Prague participated in the experiment. Participants were familiarized twice with the testing protocol before the study began and were instructed not to perform any physically demanding activities three days prior to testing. All soldiers were healthy for the duration of the experiment and did not suffer from any disease during the study period. The inclusion criteria were front kicking training for at least 2 years, the absence of muscle soreness, the absence of any musculoskeletal injury for 2 months prior to the study and 2 years of special forces training. All the participants were informed of the testing protocols and all aspects of the study before they provided written informed consent. Additionally, written informed consent was obtained from participants pictured in Figure 1 for the publication of their images.

Dynamics of the front kick

The kinetics of each front kick was measured using a triaxial force plate (Kistler 9281; Winterthur, Switzerland), recording at a sampling rate of 1000 Hz. In the preanalytical phase, the lower limit of the magnitude of the acting force was set at 100 N to reduce noise on the force plate and mark the beginning and end of the interaction between a participant's foot and the force plate. The plate was adjustable along the vertical axis to ensure that the height of the plate was individualized to each participant's "mid-range" height (Dworak et al., 2008; Kuragano and Yokokura, 2012; Vágner et al., 2018) for the purposes of the experiment (Figure 1).

The peak impact force (IF_{peak}) was determined as the maximum value of the sum of force exerted in all three directions x, y, z (Dworak et al., 2008) (Eq. 1, Figure 1). Figure 1 shows an example of the force-time curve for a single front kick (Ramakrishnan et al., 2018).

$$\left|\overrightarrow{F_{peak}}\right| = \max\left(\sqrt{\overrightarrow{F_x^2} + \overrightarrow{F_y^2} + \overrightarrow{F_z^2}}\right) \qquad \text{(Eq. 1)}$$

The time to peak force in each front kick was analyzed from the first 20 N interaction of a participant's foot with the force plate (t_0) to reaching the peak force $\left(t_{peak}\right)$ (Eq. 2).

$$(t_{max}) = \left(t_{peak}\right) - (t_0) \qquad \text{(Eq. 2)}$$

The impulse of the impact force acting during the whole time (t_{max}) of a front kick was derived from the general formula for the impulse (Eq. 3) and was modified for the discrete data measured by the force plate. For each time period (Δt), defined by the sampling frequency, the impulse was calculated. By summing them, the overall net impulse of a front kick was determined (Eq. 4) (Vágner et al., 2018).

$$\vec{I} = \int_{t_0}^{t} \overrightarrow{F}\, dt \qquad \text{(Eq. 3)}$$

$$\overrightarrow{I_{net}} = \sum_{i=1}^{n} \left(\overrightarrow{F}\right)_i \cdot \Delta t_i \qquad \text{(Eq. 4)}$$

Velocity of the front kick

Three-dimensional kinematic data were collected using a six-camera motion analysis system (Qualisys 2.2, Sweden) set up to sampling frequency of 500 Hz. Velocity data were collected from retro-reflective markers placed on the participant's malleolus lateralis to represent the foot velocity, which was gathered from the peak marker velocity before the impact initiation on the force plate. The force plate and 3D motion capture data were fully synchronized and collected using Qualisys software 2.2 (Qualisys Track Manager, Sweden). The impact velocity (V_{imp}) was gathered from the lateral malleolus marker from the 10 ms time frame prior to the first recorded 2 N impact to the force plate.

Isokinetic strength testing

All isokinetic strength tests were performed using a standard dynamometer (Humac Norm; CSMi Stoughton, MA, USA), where the peak moments of the Hip_{flex} and Hip_{ext} of the kicking dominant limb and internal and external Hip_{Rot} of the non-dominant lower limb (stance limb during kicking) were measured at different angular velocities (Stastny et al., 2018). In addition to the peak force measurement, the antagonist ratios were calculated from the values of the peak moments. Calibration of the unit was performed at the beginning of each test day according to the 502140 HUMAC NORM guidelines.

Hip_{flex} and Hip_{ext} were tested in the supine position with the dynamometer lever arm aligned with the axis of the femur great trochanter at the angular velocities of 30°·s^{-1}, 120°·s^{-1}, 240°·s^{-1} and 300°·s^{-1}. For each velocity, the participant performed six antagonist consecutive repetitions of maximum voluntary contraction in concentric muscle action, with a 90 s rest interval between the tested velocities. The movement of Hip_{flex} and Hip_{ext} was accomplished within the possibility of the individual range of motion of each participant with a minimum range of 120° of Hip_{flex}.

The internal and external Hip_{Rot} were tested in the supine position with the extended knee and the hip joint at angular velocities of 30°·s^{-1} and 90°·s^{-1}. Each participant performed three repetitions of the maximum voluntary contraction at concentric and eccentric muscle action in two sets. The dynamometer was set up to perform concentric internal and external Hip_{Rot} in antagonist action, followed by eccentric internal and external Hip_{Rot}, where each maximal effort was followed by a 90 s rest interval. Movement of the internal and external Hip_{Rot} was accomplished within the possibility of the individual range of motion of each participant with a minimum range of 35° of the internal and external Hip_{Rot}. The ratios between concentric contractions were called conventional ratios and those between eccentric and concentric actions were called functional ratios.

Statistics

All statistical analyses were performed using NCSS version 2004 (Number Cruncher Statistical Systems, Kaysville, Utah) with the alpha level set at 0.01. The mean and standard deviation of all six kicks and all isokinetic measurements were calculated along with the intraclass correlation coefficient across performed repetitions (ICC). The Shapiro-Wilk and Kolmogorov-Smirnov tests were used to determine whether the data were normally distributed. In the event of normal distribution, the Pearson's product moment correlation coefficient was used to examine the relationships between the isokinetic data vs. velocity and impact force of front kicks. The reliability of the isokinetic peak torque, kick velocity and impact force variables were estimated by the intraclass correlation coefficient (ICC).

First, a simple linear regression was created, followed by multiple regression and the construction of a regression model. The isokinetic data that significantly correlated ($p < 0.01$) with the front kick performance measurements were used in the basic regression model as predictors to construct a linear regression model to determine the IF_{peak}. Furthermore, we used isokinetic data that were not significantly correlated with the IF_{peak} to extend the basic regression model.

Results

The average impulse force of the front kick was 2202 ± 489 N, and average velocity of the front kick was 7.7 ± 1.03 m·s^{-1}, where all the repeated measurements showed high reliability (ICC above 0.90) and data normality was not disrupted (Table 1). However, most highly correlated values were observed between V_{imp} and internal Hip_{Rot} concentric and eccentric 90^{0}s (r=0.22, *p*=0.28 and 0.36, *p*=0.08), internal/external Hip_{Rot} conventional ratio 30·s (r=0.28, *p*=0.18) and internal/external functional Hip_{Rot} 30^{0}·s (r=0.22, *p*=0.30), but without significance. Additionally, no correlation was found between V_{imp} and Hip_{flex} or Hip_{ext} concentric and the IF_{peak}.

Hip rotation (stance lower limb)

No significant correlation was observed between Hip_{Rot} and the IF_{peak} of the front kick. The correlation revealed high values between the IF_{peak} of the frontal kick and External Hip_{Rot} Ecc 90^{0}·s (r=0.31, p = 0.13), Internal Hip_{Rot} Ecc 90^{0}·s (r = 0.21, *p*=0.30), but both were not significant. Additionally, no relationship was found between the IF_{peak} of the front kick vs. the internal/external conventional and internal Ecc/external functional Hip_{Rot} peak torque.

Hip flexion and extension (kicking lower limb)

A significant correlation was observed between the IF_{peak} of the front kick and Hip_{flex} and Hip_{ext} moment. The high correlation was observed between the IF_{peak} and Hip_{flex} concentric at 120°·s (r = 0.64, $p < 0.001$) and Hip_{ext} concentric

120°·s (r = 0.72, $p < 0.001$). A moderate correlation was found between the IF_{peak} and concentric Hip_{ext} at 30°·s, 240°·s and 300°·s (r = 0.53, 0.61, 0.59, respectively, $p < 0.001$). Since the Hip_{flex} and Hip_{ext} concentric at 120°·s showed the highest values, this component was used as the first factor in a further regression model. Linear regression showed a relationship between the IF_{peak} and concentric Hip_{flex} at 120°·s (R^2 = 0.41; $p < 0.001$, Figure 2) and Hip_{ext} at 120°·s (R^2 = 0.51; $p < 0.001$, Figure 2). When a linear regression model was constructed using these two variables as one component to the predicted IF_{peak} of the front kick, the predictive power of the model was 54% of the variability (R^2 = 0.54; $p < 0.001$) (Figures 2 and 4).

Figure 3 shows that participants who achieved high levels of Hip_{flex} and Hip_{ext} and had more weight achieved a better IF_{peak}. The correlation coefficients between the body mass of participants vs. Hip_{flex} and Hip_{ext} moment were r = 0.54 (p = 0.005) and r = 0.38 (p = 0.06), respectively. Additionally, the correlation coefficient between the body mass of participants vs. IF_{peak} was r=0.46 (p=0.02). Therefore, we calculated the relative values of the IF_{peak} per kg of body mass. The correlation coefficient between the IF_{peak} and a relative IF_{peak} per kg of body mass was r = 0.94 (p = 0.001). When body mass was used as a partial variable, the relationship between the IF_{peak} and isokinetic variables was decreased by 8%.

Hip flexion, extension and rotation (kicking and standing leg)

The regression model using concentric Hip_{flex} and Hip_{ext}120°·s as a separate component combined with the component of concentric and eccentric Hip_{Rot}Con at 30°·s^{-1} increased the IF_{peak} prediction by 12% (R^2=0.66; p=0.0016). Additionally, when we added to this component the model of Internal/external conventional Hip_{Rot} at 30°·s^{-1} and internal eccentric/external concentric functional Hip_{Rot} at 30°·s^{-1}, the prediction of the IF_{peak} of the front kick was 71% of the variability (R^2 = 0.71; p = 0.0033). The last variable component that we could add to the regression model was the conventional ratio between Hip_{flex}/Hip_{ext} at 300°·s^{-1}, which increased the IF_{peak} prediction by 4% (R^2 = 0.75; p = 0.0031). This model comprised independent variables that were mentioned above predicted 75% of the variability in the IF_{peak} of the front kick (Figure 4).

Discussion

Although various techniques, conditions and tactical aspects may be related to the front kick IF_{peak}, our study showed that the isokinetic strength of hip flexion and extension are strong physical components predicting the amount of IF_{peak}, which can explain more than half of its value. Moreover, this finding indicates that not maximal strength, but explosive strength and speed strength of hip flexors and extensors should be the target of kick-specific testing and training. On the other hand, our study did not include knee extensors and flexors as in some previous studies (Busko, 2016; Ramakrishnan et al., 2018) and may be added in future studies to design an even more complex and stronger regression model. However, the principal goal of isokinetic testing is to use a rather smaller amount of the testing task, but with high validity for the tested population purposes. Based on the high regression of our first independent component of hip flexion and extension at 120°·s^{-1}, we can conclude that testing only those two muscle groups may provide valid information about the physical ability to perform the front kick with a high IF_{peak} in highly trained soldiers.

Our regression model has four components, where 17% of the variance is explained by the maximum concentric and eccentric strength of hip external and internal rotation regarding the stance of the lower limb. This result supports a practical approach of the front kick technique, where stance limb rotation should highly contribute to the beginning of a kick and should support the whole body during the foot impact. Therefore, we may conclude that hip rotation typical for round kicking (Sujae and Koh, 2010) should also be beneficial in front kick training.

Table 1

Isokinetic net moment during hip external rotation, internal rotation, hip flexion, extension and their strength ratios at different movement speeds

Peak moment (N·m)	Average ± SD	CI lower	CI upper	SW	KS
External Hip Rotation Con 30°·s	68 ± 17	61	75	0.97	0.08
Internal Hip Rotation Con 30°·s	57 ± 11	52	61	0.97	0.09
External Hip Rotation Con 90°s	65 ± 16	58	71	0.98	0.10
Internal Hip Rotation Con 90°·s	52 ± 10	48	56	0.98	0.13
External Hip Rotation Ecc 30°·s	83 ± 23	73	92	0.90	0.21
Internal Hip Rotation Ecc 30°·s	60 ± 16	53	67	0.72	0.20
External Hip Rotation Ecc 90°·s	81 ± 25	71	92	0.88	0.24
Internal Hip Rotation Ecc 90°·s	61 ± 10	57	66	0.96	0.13
Internal/external Conv 90°·s	0.82 ± 0.16	0.76	0.89	0.95	0.12
Internal/external Conv 30°·s	0.85 ± 0.17	0.79	0.92	0.95	0.14
Internal ecc/external Functional 90°·s	0.99 ± 0.23	0.90	1.09	0.97	0.10
Internal ecc/external Functional 30°·s	0.91 ± 0.23	0.82	1.00	0.96	0.10
Hip flexion Con 30°·s	186 ± 31	173	199	0.98	0.12
Hip extension Con 30°·s	362 ± 78	329	132	0.95	0.14
Hip flexion Con 120°·s	143 ± 27	132	155	0.96	0.11
Hip extension Con 120°·s	281 ± 57	257	304	0.96	0.14
Hip flexion Con 240°·s	109 ± 23	99	118	0.97	0.09
Hip extension Con 240°·s	217 ± 56	194	240	0.97	0.07
Hip flexion Con 300°·s	94 ± 22	85	103	0.97	0.08
Hip extension Con 300°·s	208 ± 54	186	230	0.96	0.08
Hip flexion/extension 30°·s	0.53 ± 0.09	0.37	0.72	0.97	0.11
Hip flexion/extension 120°·s	0.52 ± 0.07	0.39	0.69	0.98	0.11
Hip flexion/extension 240°·s	0.52 ± 0.11	0.35	0.82	0.94	0.12
Hip flexion/extension 300°·s	0.47 ± 0.11	0.29	0.78	0.92	0.15

Con = concentric, ECC = eccentric, SD = standard deviation, SW = Shapiro-Wilk test, KS = Kolmogorov-Smirnov test, CI = confidence interval, Conv = conventional strength ratio.

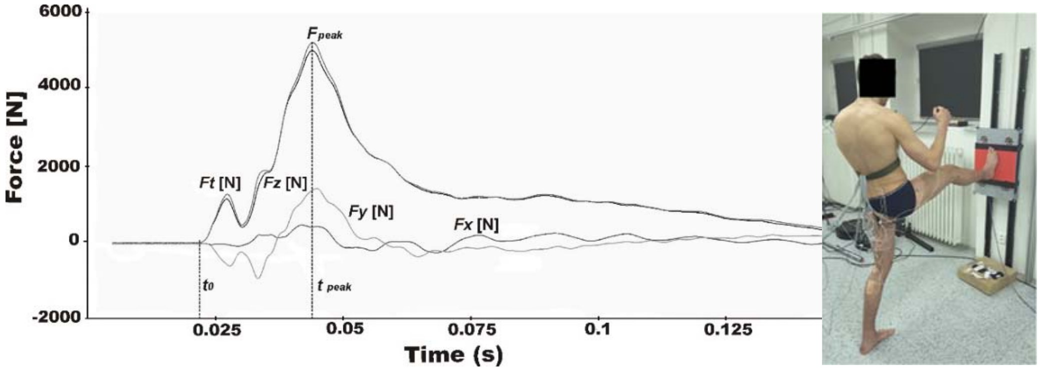

Figure 1

A participant performing the front kick to a vertically anchored force plate and the time course of the kinetic force recorded during the kick.

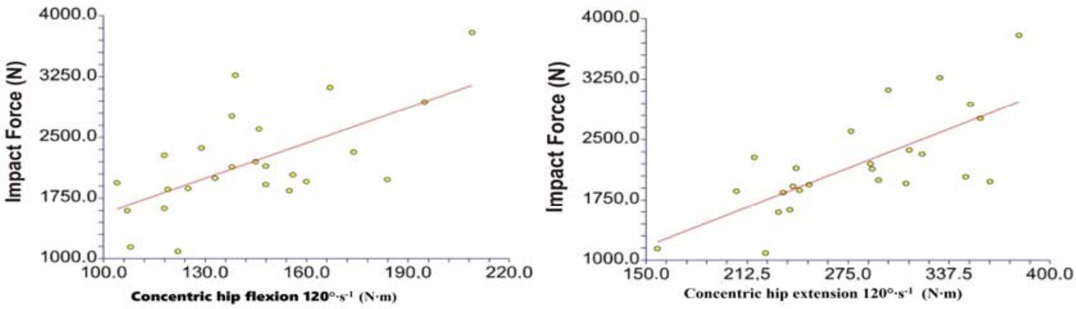

Figure 2

Regression of the impact force of the front kick vs. concentric hip extension at 120°·s and vs. concentric hip flexion at 120°·s^{-1}

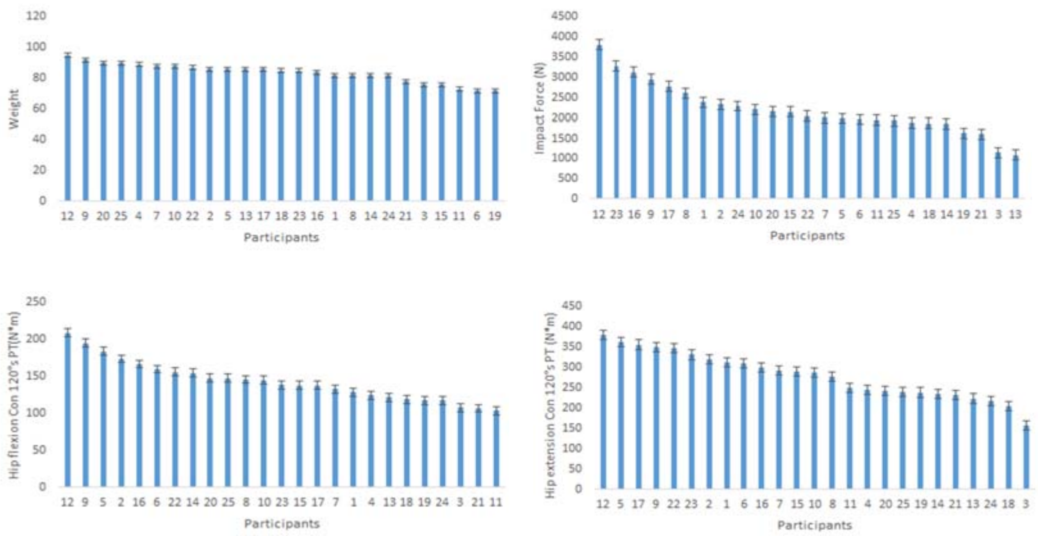

Figure 3

Con hip extension 120°·s, con hip flexion 120°·s, body mass and impact force delivered by individual participants with error bars showing the maximum and minimum values.

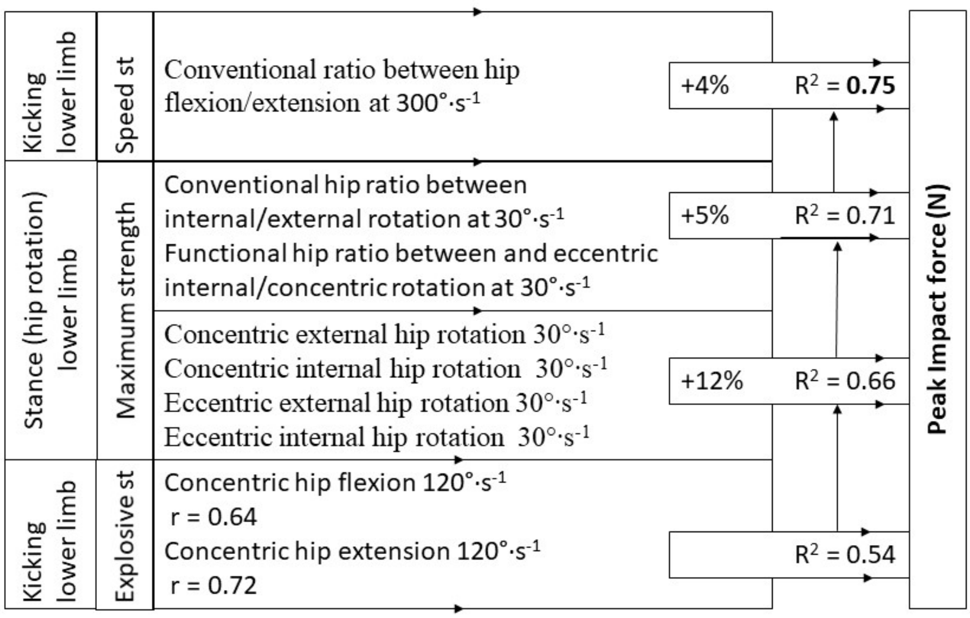

Figure 4

Composite regression model from isokinetic variable predictors. St = strength

The finding that the hip rotation ratio and eccentric rotator strength appear in our model supports that those muscles contribute when kicking is accelerated, but also when kinetic energy is being transferred to the target. On the other hand, our study found a correlation between body mass and the IF_{peak}, while a previous study between body mass and energy transfer to the target (Ramakrishnan, et al., 2018) regardless of training levels of kickers. This suggests that the body mass is an important aspect of the kicking IF_{peak}. The effect of body mass on the increase in the stroke force was found in correlation studies (Estevan et al., 2011; Pędzich et al., 2006). However, this fact did not reduce significantly our regression model, which was composed of isokinetic variables. We believe that if the soldier's body can keep a high level of stability on the stance leg during the kick, the probability of transfer energy to the target increases.

The isometric strength of Hip_{flex} and Hip_{ext} is documented in combat sports (boxing, judo, taekwondo), where the average Hip_{flex} 98 Nm and Hip_{ext} 427 Nm (Busko, 2016) have been reported. Values of Hip_{flex} (186 ± 31 Nm) and Hip_{ext} (362 ± 78 Nm) at 30°·s-1 obtained in the present study are not comparable due to the differences in the isokinetic protocol and a different study population. However, we can state that our military professionals had more balanced Hip_{flex}/Hip_{ext} strength ratios than combat sport athletes, which may refer to their complex strength development of the lower limb antagonist groups. Previous studies assume the high importance of the isokinetic knee flexion moment, knee extension moment thigh adductors and thigh adductors moment (Jung et al., 2017; Probst et al., 2007) for kicking performance in karate and taekwondo athletes. Our study did not include these muscle groups based on the assumption that strength of the knee extension and flexion cannot be fully applied in complex movement without sufficient strength development of Hip_{flex} and Hip_{ext}. With regard to hip adductors and abductors, we preferred a deeper muscle group of hip rotators, of which function is directly responsible for whole-kick stability. Our results showed that the hip internal and external strength ratio is an independent component in our model, where our participants had a functional ratio as high as 0.91 ± 0.23. This supports our hypothesis that not just individual muscle strength, but also antagonist balance plays an important role in kicking efficiency. Although our regression model resulted in a high amount of the explained variable, we still recommend estimating the role of knee extensors and flexors in future studies.

Since no current normative data exist about the IF_{peak}, we cannot categorize our average value of 2.2 ± 0.5 kN to a performance level. However, our data are in the range of previously reported IF_{peak} values of 1.17 - 7.79 kN, where athletes or soldiers from different martial arts reported average values of 3.89 kN (Ramakrishnan et al., 2018), 2.9 kN (Dworak et al., 2008), and 3.4 kN (Vágner et al., 2018). The average V_{imp} of the front kick was 7.7 ± 1.03 m·s^{-1}. Nevertheless, no correlation was found between V_{imp} and isokinetic variables or IF_{peak}, a finding that is similar to a study performed on soccer players (Mognoni et al., 1994). Therefore, we can conclude that the level of isokinetic strength of the muscle is not related to the velocity of the kick.

Our results should be used in military personnel and combat sport training, where we recommend exercising antagonist muscle groups and hip stabilizers (Stastny et al., 2016), preferably in a unilateral fashion (Stastny et al., 2015a, 2015b) and regulating the exercise tempo during the eccentric muscle action (Wilk et al., 2018a, 2018b). The hip flexors and extensors should be progressively trained for maximum strength, followed by explosive strength development and at the final stages of conditioning programs for speed strength, to improve the efficiency of the front kick. The internal and external hip rotators should be trained in unilateral and antagonist exercises focusing on maximum strength and eccentric muscle action, to improve the efficiency of the front kick.

One limitation of the present study is that the setup of the testing procedure was not identical to the environment of outdoor practices, but simulated well-prepared, kick-adjusted (optimal) and self-started front kicking action. Moreover, our regression model did not include a range of hip motion, the strength of all lower limb muscle groups, the kick accuracy and any perceptional requirements.

Conclusions

The explosive strength of kicking limb hip flexors and extensors is the main condition constraint for kicking performance. Therefore, exercises enhancing explosive strength should be included in programs focused on front kicking. Maximum strength of the stance limb internal and external rotators and speed strength of kicking limb hip flexors and extensors are important constraints of kicking performance and should be considered in improving the front kick. The external and internal rotators should be trained by concentric and eccentric contractions with equal strength of both antagonists.

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